2006

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10.1123/ijsnem.22.6.430
This is an Author's Accepted Manuscript of: Journal of Strength and Conditioning Research (2006) 20(1), 108 - 11.
Available here.

Journal of Strength and Conditioning Research, 2006, 20(1), 108–116
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RESPONSES OF ELBOW FLEXORS TO TWO STRENUOUS ECCENTRIC EXERCISE BOUTS SEPARATED BY THREE DAYS

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ABSTRACT. Chen, T.C., and K. Nosaka. Responses of elbow flexors to two strenuous eccentric exercise bouts separated by three days. *J. Strength Cond. Res. 20(1):108–116. 2006.*—This study investigated whether the second eccentric exercise performed 3 days after the initial bout would exacerbate muscle damage and retard the recovery. Fifty-one athletes performed 30 eccentric actions of the elbow flexors using a dumbbell weighted 100% of the maximal isometric force (MIF) at the elbow joint angle of 90° (ECC1). Three days after ECC1, all subjects except those in the control group ($n = 12$) performed the second bout (ECC2) with the same (100%) intensity ($n = 12$), 90% ($n = 13$), or 80% ($n = 14$) of the ECC1. Some subjects, especially in the 100% group, required spotting for ECC2 but made maximal effort to complete the exercise. MIF, range of motion, upper-arm circumference, muscle soreness, muscle proteins in the blood, and ultrasound images were used to assess muscle damage. Changes in these measures for 9 days following ECC1 were compared among groups by 2-way analysis of variance (ANOVA) with repeated measures. All criterion measures changed significantly after ECC1; however, no significant differences between the groups were evident for any of the changes in the measures. These results suggest that it is possible for athletes to complete the second bout if the intensity is reduced 10–20% from the initial bout. No significant differences between the control group and other groups indicate that the second eccentric exercise performed 3 days after the initial bout does not exacerbate muscle damage and retard the recovery regardless of the intensity of the second bout. It is concluded that the elbow flexors can perform high-intensity eccentric exercise in the early stage of recovery from the initial bout and are not damaged further by performing a subsequent bout 3 days after the first.

KEY WORDS. maximal isometric force, creatine kinase, ultrasonography, muscle soreness

INTRODUCTION

Delayed onset muscle soreness (DOMS) occurs when unaccustomed exercise is performed or the volume or intensity of exercise exceeds an ordinary level (7, 10, 14). DOMS generally develops 8–12 hours after exercise, peaks between 24 and 72 hours, and disappears by a week following exercise (1, 10, 13, 14). DOMS is one of the symptoms of muscle damage (12, 13, 34); however, it does not necessarily reflect the time course and the magnitude of muscle damage (27). It has been documented that DOMS is related to connective and/or contractile tissue microtrauma initiated by high tension and strain produced during eccentric muscle actions (1, 2, 7, 13) and inflammatory responses after the injury (5, 18, 21). Eccentric exercise-induced muscle damage is repairable; however, the time required for complete recovery is dependent on the magnitude of muscle damage (6, 13).

Previous studies have shown that muscles need several weeks to recover from unaccustomed strenuous eccentric exercise (12, 13, 20, 26). However, subsequent training bouts are often performed before complete recovery from the previous bout. Frequency is a key factor for maximizing training effects, and it is recommended to perform resistance training at least 2 days per week for improving muscle size and strength (4, 17). Athletes repeat a training regimen that stimulates the same muscle groups every 3–4 days (3, 4). To follow this training frequency, resistance training is often performed when muscles are still experiencing DOMS and recovering from damage (1). In fact, it is generally recommended to perform training while ignoring DOMS (1, 36). However, it is yet to be clarified how sore and impaired muscles from previous training respond to additional strenuous stimuli.

Several studies have reported that repeating the same eccentric exercise bout 2 or 3 days following the first bout does not exacerbate muscle damage nor retard the recovery process (8, 25, 28, 32). However, it should be noted that the intensity of the exercise in these studies was not maximal and somewhere between 50 and 80% for both the first and second bout. It is likely that athletes use higher intensity than 80% for their training regimens and try to stimulate muscles maximally even in early stages of recovery from the previous bout. However, it has not been clarified whether the second bout of exercise exceeding 80% of the first exercise intensity exacerbates muscle damage and affects the recovery. Perhaps it is impossible to perform the same high-intensity exercise exceeding 80% of the first bout in this period, since muscle strength decreases to 40–60% of the baseline for several days following eccentric exercise of the elbow flexors (12, 13, 23, 24, 26, 34). No study has investigated the intensity that muscles can perform eccentric exercise without additional muscle damage and influence on recovery when the second bout is performed 3 days after the first bout.

It is also important to note that the previous studies (13, 23–28) used subjects who were "untrained" or had not been involved in a resistance-training program prior to the study. To our knowledge, no study has investigated the responses of "athletes" who perform resistance training in their regular training to 2 bouts of strenuous eccentric exercise of the elbow flexors separated by 3 days. It might be that only trained individuals can perform 2 bouts of strenuous eccentric exercise separated by 3 days. The present study was designed to reflect a preseason

resistance training of athletes and to answer the questions of whether it would be possible to perform the same high-intensity eccentric exercise within 3 days after the first bout, and whether the subsequent bouts of the high-intensity eccentric exercise exacerbates muscle damage or DOMS.

Thus, this study investigated the response of elbow flexors to the second bout of eccentric exercise performed at 80–100% of the first bout intensity 3 days after the initial eccentric exercise bout of maximal intensity using athletes. It was hypothesized that muscle damage would be exacerbated and the recovery would be retarded when the intensity of the second training bout exceeded the capacity of muscles to control eccentric muscle actions, even for the trained athlete.

METHODS

Experimental Approach to the Problem

This study was designed to investigate the maximal intensity of the second exercise bout that could be performed without exacerbating muscle damage and retarding the recovery for athletes who had been performing resistance training for several years. Previous studies (9, 23, 25, 32) using untrained subjects reported that maximal isometric force after performing "100%" intensity exercise was approximately 70–80% of the pre-exercise level at 3 days postexercise. This study set the intensity of the second bout at 80, 90, and 100% and hypothesized that the maximal intensity would be around 80%; the intensity above this level would be difficult to perform and might induce further damage. All groups performed the same intensity exercise for the first bout; however, the intensity for the second bout, which was performed 3 days after the initial bout, was either the same as the first bout (100%), 10% lower (90%), or 20% lower than the first bout (80%). One group did not perform the second bout and was placed as a control (CON) group. Maximal isometric force, range of motion, upper-arm circumference, muscle soreness, muscle proteins in the blood, and ultrasound images were used to assess the magnitude of muscle damage. Changes in these measures were compared among groups to examine whether the changes were influenced by the second bout and the intensity of the second exercise bout.

Subjects

This study recruited both men (n = 41) and women (n = 10) as subjects. Controversy exists concerning the gender differences in response to eccentric exercise; however, several recent studies (11, 29, 31) have reported no significant gender differences in maximal isometric strength loss and soreness after high-force eccentric exercise. It would had been better to have the same number of male and female subjects in this study, but fewer women had equivalent athletic backgrounds compared with the men, which made the subject numbers unequal in this study. All subjects gave a written informed consent document consistent with ethical standards at National Chiayi University, which were accordance with the Helsinki Declaration of 1975. The mean age, height, and body weight were 20.5 ± 2.1 years, 171.3 ± 7.5 cm, and 64.5 ± 6.5 kg, respectively. All subjects were student athletes and trained at least 5 days (14 h) a week for their sports such as soccer, basketball, handball, badminton, shooting, swimming, and track and field. They had been performing their specified sport for 7–10 consecutive years. In their regular training, they reported performing resistance training 2–3 times per week for preseason, and once per week for in-season for the past year. A typical resistance training regimen for these athletes included 10 exercises such as hip sled or back squat, forward lunge, flat bench press, leg extension/curl, bent-knee sit-up, standing calf raise, lat pulldown/back pulldown, wrist curl/extension, biceps curl, machine shoulder press, vertical chest press, and seated dumbbell triceps extensions. (For the first stage of preseason: intensity, 40–60% 1 repetition maximum [1RM]; sets/bout, 3–4; repetitions, 12–20; rest between sets, 30–90 s; training duration, ~10 weeks. For the second preseason stage and in-season: intensity, 70–80% 1RM; sets/bout, 3–4; repetitions, 8–12; rest between sets, 60–90 s; training duration, ~15 weeks.) All subjects participated in this study in their off-season and were requested not to perform any unaccustomed exercise or vigorous physical activities during the experimental period. They were also asked not to take anti-inflammatory drugs or nutritional supplements during the study. Maximum isometric force (MIF) was measured before the first exercise bout, and subjects were placed into 4 groups by matching the pre-exercise MIF level among the groups. The groups were made based on the exercise intensity for the second bout: 100% (n = 12), 90% (n = 13), and 80% (n = 14), plus a control group (n = 12) that did not perform the second exercise bout was also included. No significant differences in the physical characteristics including muscle strength of the elbow flexors were evident among the groups.

Procedures

Exercise. All subjects performed the first eccentric exercise bout of the elbow flexors (ECC1) of their nondominant arm using a dumbbell that was set at 100% of each subject's MIF at the elbow angle of 90° (1.57 rad). It should be noted that the elbow flexors generate maximal isometric strength around the elbow joint angle of 90°; however, the strength decreases as the increasing elbow joint angle moved toward a more extended position and reaches approximately 50–70% of that at the 90–100° extended position (25, 36). The average dumbbell weight used in ECC1 for the 100%, 90%, 80%, and control groups were 27.9, 27.4, 27.9, and 27.7 kg, respectively, with no significant differences between the groups. For each eccentric action, subjects were asked to lower the dumbbell from an elbow flexed (50°, 0.87 rad) to an elbow extended position (170°, 2.97 rad) in 3~4 seconds. After completing each eccentric action, the examiner removed the dumbbell at the elbow extended position, and the subject returned the arm to the flexed position without load. Subjects performed 30 eccentric actions with a 45-second rest between actions. The relatively long rest time was adequate for subjects to perform the eccentric actions precisely. The total exercise time was approximately 2 minutes (3~4 seconds × 30 actions), and the total time including the exercise and rest (45 seconds × 29 actions) was approximately 24 minutes. Subjects were verbally encouraged to maximally resist against the action throughout the range of motion, and the examiner instructed the about subjects the lowering velocity of the dumbbell by counting "0" for the beginning and "1, 2, 3, and 4" for the movement.

Three days after ECC1, subjects in the 100% group repeated the same exercise as ECC1, but subjects in the 80 and 90% groups repeated the second bout with 20 and 10% lighter dumbbells than that of ECC1, respectively. The protocol for the second bout (ECC2) was the same as that of ECC1. When subjects were not able to control the lowering velocity, the examiner spotted as minimally as possible to avoid a fast extension movement. Spotting was limited to the muscle-lengthened angles for most of the cases, and the examiner encouraged the subjects to make maximal effort throughout the range of motion. Subjects in the control group did not perform ECC2.

Although the subjects had performed resistance training regularly prior to the involvement in this study, they reported that they had not performed such a "pure" eccentric exercise of the elbow flexors performed in this study.

Criterion Measures. MIF, range of motion (ROM), upper-arm circumference (CIR), serum creatine kinase (CK), lactate dehydrogenase (LDH), and myoglobin (Mb) levels were measured before and immediately after both ECC1 and ECC2, and every 24 hours for 9 consecutive days after ECC1. Muscle soreness was assessed before and for 9 consecutive days after ECC1. Ultrasound images were taken from the upper arm 2 days before ECC1 and 2, 4 (1 day after ECC2), and 9 (6 days after ECC2) days after ECC1 for all groups. These parameters have been shown to change significantly for at least several days following exercise when muscle damage is induced (7, 12, 13, 23, 24).

Maximal Isometric Force. MIF was recorded for 3 seconds at the elbow angle of 90° (0.87 rad) on a modified arm curl machine using a force transducer (Model UG, Biopac Systems, Inc., Santa Barbara, CA) connected to a digital recorder (TSD150, Biopac Systems). Three trials were performed with 1-minute rest between each contraction, the peak value of each was obtained, and the average of the 3 trials was used for further analysis (8).

Elbow Joint Angles and ROM. Flexed (FANG) and relaxed (RANG) elbow joint angles were measured 3 times for each time point using a goniometer (Creative Health Products, Plymouth, MI). FANG was assessed when the subjects tried to fully flex the elbow to touch the shoulder by the palm while keeping the elbow at the side. RANG was the angle where the subjects relaxed the arm allowing it to hang down by the side. A semipermanent marker was used to identify the landmarks such as the lateral center/middle point of the humerus (near to shoulder joint or between greater tubercle and lesser tubercle), the lateral center/axis point of cubital/elbow joint, and the lateral middle/center point between radius and ulna (near to wrist/carpal joint) for the goniometer placements. ROM was calculated by subtracting FANG from RANG (8, 13, 23, 24).

Upper-arm Circumference. CIR was measured 3 times at 4 and 8 cm above the elbow joint with a Gulick tape measure while allowing the arm to hang down by the side of the body (8, 23, 24). These 2 points were marked on the subject's arm to ensure consistent placement of the tape measure, and the mean value of the three measurements was used for the analysis.

Blood Markers. Ten milliliters of venous blood was collected by venipuncture from the cubital fossa region of the dominant arm into a serum separation tube. The blood was allowed to clot for 30 minutes at room temperature and then centrifuged for 10 minutes to obtain serum. After separation, all serum samples were stored at −20°C until analysis for CK and LDH activities and myoglobin Mb concentration. Serum CK and LDH activities were determined spectrophotometrically by a Genstar chemistry analyzer (Electro-Nucleonics, Fairfield, NJ) using test kits (Sigma Diagnostics, St. Louis, MO). Serum Mb concentration was measured by a biochemical analyzer (Model ADVIA-Centaur, Bayer Co. Ltd., Germany) using a test kit (Denka-Seiken Co. Ltd., Japan). Samples were analyzed in duplicate, and the mean of both measures was used for subsequent statistical analysis. The normal reference ranges for CK, LDH, and Mb were 38–174, 91–180, and $<$ 110 $\mu g \cdot L^{-1}$, respectively.

Muscle Soreness. Muscle soreness was evaluated using a visual analogue scale of a 100-mm continuous line that represents "no soreness at all" at one side (0 mm) and "very, very sore" at the other side (100 mm). Subjects were asked to report the soreness level on the line when an investigator palpated over the biceps brachii and extended the elbow (8, 24).

Ultrasonography. B-mode ultrasound pictures of the upper arm were taken from the 0–4 and 4–8 cm of the biceps brachii by using an Acuson Aspen Ultrasound System (Acuson Co., Mountain View, CA) with a 7.5-MHz linear probe. To obtain the ultrasound images, the probe was placed on the upper arm to get images of biceps brachii and brachialis by using the same marked sites used for the circumference measures (4 and 8 cm from the elbow joint) while subjects were sitting on a chair with their forearm on an armrest. The transverse images were obtained from the 2 sites (4 and 8 cm from the elbow joint), and the longitudinal images were also taken by placing the probe between the 2 marks. The gains and contrast were kept consistent over the experiment period, and all images were saved in a magneto-optical disc as discom files. These saved images were transferred to a computer as bitmap (.bmp) files and analyzed by a computer image analysis software (Amira 3.0, Mercury Computer System, Inc., San Diego, CA). The thickness of the elbow flexors was determined by measuring the distance between the subcutaneous fat layer and the edge of the humerus (24, 26) on the transverse images of the biceps brachii and brachialis (see Figure 6). The average echo intensity for the region of interest (ROI; $2 \times 2 = 4$ cm^2) was calculated by the computer image analysis software that provided a histogram of gray scale (0, black; 100, white) for the ROI. The relative increase in the echo intensity from the pre-ECC1 value was calculated for each subject.

Statistical Analyses

Based on several previous studies (8, 25, 26) have shown that the intraclass correlation coefficient (ICC) for MIF, ROM, and CIR, and they were more than 0.91, 0.96, and 0.97, respectively. In the present study, a similar ICC was obtained for MIF (0.96), ROM (0.89), and CIR (0.96).

Data were analyzed with a 2-way mixed model analysis of variance (ANOVA) with repeated measures over time and grouped as a between-subjects factor. If the ANOVA detected significance, a Tukey post hoc test was performed. Statistical significance was set at $p \leq 0.05$. Data are presented as means $\pm$ *SEM*, unless otherwise stated.

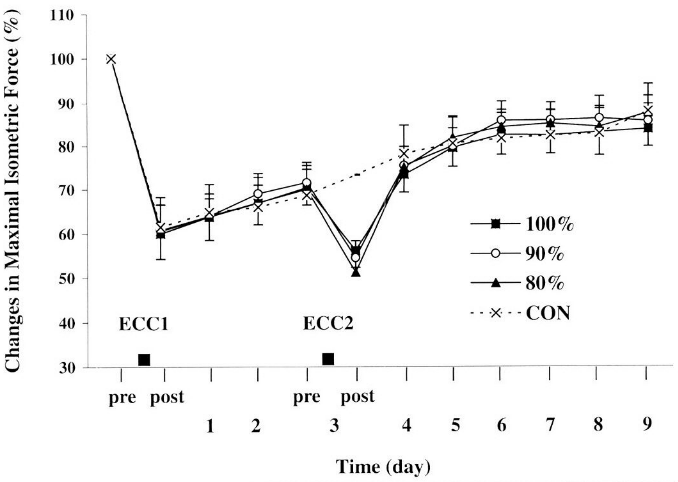

FIGURE 1. Normalized changes in maximal isometric force (means ± *SEM*) from the baseline (pre, 100%) and for 9 days following the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group, and the values immediately after ECC2 are shown as the second "post."

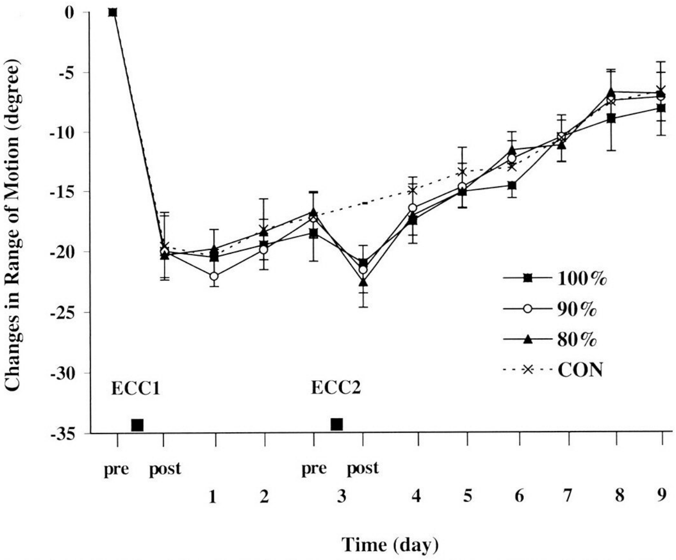

FIGURE 2. Changes in range of motion (means ± *SEM*) from the baseline (pre, 0) and for 9 days following the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group, and the values immediately after ECC2 are shown as the second "post."

RESULTS

Exercise

All subjects were able to complete the first exercise bout in the manner expected, and no spotting was required. For ECC2, all subjects in the 80% group and most of the subjects (10/13) in the 90% group were able to perform the 30 eccentric actions as instructed. However, most of the subjects (9/12) in the 100% group had a problem of controlling the dumbbell at the elbow joint angle exceeded 140° (2.44 rad), especially toward the end of the exercise, but all completed the 30 eccentric actions. When spotting was required, the investigator made the subjects generate maximal force by giving minimal support to keep the slow lowering action of the dumbbell for the whole range of motion. The amount of assistance varied among subjects; however, in the opinion of the investigator, all subjects generated maximal effort even when spotting was applied.

Maximal Isometric Force

Before ECC1, MIF for the 100%, 90%, 80%, and control groups were 27.9 kg (273.5 ± 22.2 N), 27.4 kg (268.0 ± 21.2 N), 27.9 kg (273.8 ± 20.6 N), and 27.7 kg (271.4 ± 21.4 N), respectively, with no significant difference between the groups. MIF decreased significantly ($p < 0.01$) to approximately 60% of the pre-exercise level immediately after ECC1 and recovered to about 70% of the baseline 3 days after ECC1 for all groups with no significant ($p > 0.01$) difference between the groups (Figure 1). The control group showed gradual recovery from 3 to 9 days postexercise, but MIF was still about 12% lower than the pre-exercise value at 9 days postexercise. This was also the case for other groups that performed ECC2 at 3 days after ECC1. Although there was a small further decrease ($p < 0.05$) in MIF immediately after ECC2 for the 100% (56.1%), 90% (54.5%), and 80% (51.2%) groups, MIF recovered to the same level as the control group by the next day after ECC2 for all groups.

Range of Motion

ROM decreased significantly ($p < 0.01$) following ECC1, and the amount of decrease was approximately 20° immediately after ECC1. ROM did not show a recovery for the next 2 days, but started to recover after 3 days postexercise for all groups (Figure 2). No significant differences between the groups were found 4–9 days postexercise, although a small further decrease ($p < 0.05$) in ROM was found immediately after ECC2 for the 100% (21.0°), 90% (21.6°), and 80% (22.6°) groups compared with pre-ECC1 values (Figure 2).

Upper-arm Circumference

Changes in CIR at 4 and 8 cm portions were not significantly different, therefore only the data of 8 cm are shown in Figure 3. Significant increases ($p < 0.05$) in circumference were observed following ECC1 for all groups with no significant difference between the groups. CIR peaked 4–5 days after exercise, and the amount of increase was approximately 10–11 mm from the baseline for all groups. CIR did not increase significantly immediately after ECC2 for all groups (Figure 3).

Creatine Kinase, Lactate Dehydrogenase, and Myoglobin

No significant increases in serum CK (Figure 4a) and LDH (Figure 4b) activities, and Mb concentration (Figure 4c) were evident 1–2 days after ECC1 for all groups, but at 3 days after ECC1, significant elevations ($p < 0.05$) from the baseline were evident. Serum CK and LDH activities, and Mb concentration peaked 4–5 days after ECC1 for all groups and were still elevated from the baseline at 9 days after ECC1. No further significant increases in CK, LDH, and Mb were observed immediately after ECC2 for all groups, and changes in these measures were

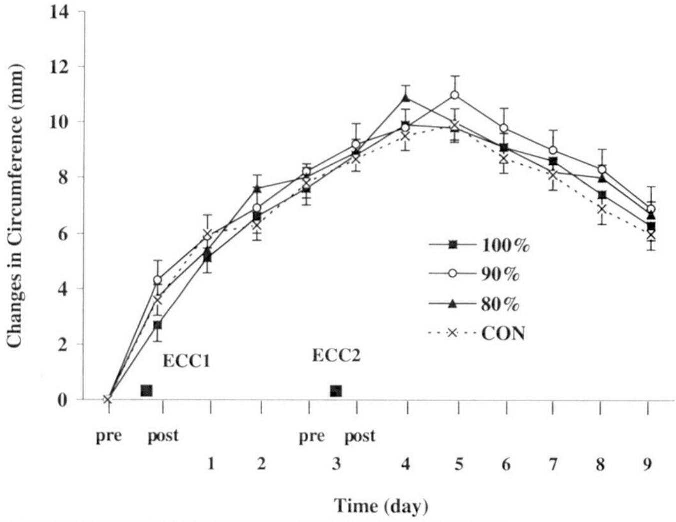

FIGURE 3. Changes in upper-arm circumference (means ± *SEM*) from the baseline (pre, 0) and for 9 days following the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group, and the values immediately after ECC2 are shown as the second "post."

not significantly different between the groups following ECC1 (Figure 4).

Muscle Soreness

Muscle soreness developed 1 day after ECC1 ($p < 0.05$), peaked at 1–3 days, and lasted for about 7 days following ECC1 for all groups (Figure 5). Peak soreness values after ECC1 with palpation for the 100%, 90%, 80%, and control groups were 49.6 ± 10.6, 57.8 ± 12.5, 55.3 ± 11.1, and 53.4 ± 10.4, respectively. No significant differences in change of soreness following ECC2 were evident between the groups. This was also the case for the soreness with extension.

Ultrasonography

Figure 6 demonstrates typical changes in ultrasound images before and after exercise of a subject who belonged to the 90% group. The echo intensity of the ROI before, 2, 4, and 9 days postexercise were 46.1 (arbitrary units), 62.7, 77.0, and 65.0, respectively, for this subject. Figure 7 shows the mean value of relative changes in echo intensity. Echo intensity increased significantly ($p < 0.05$) following ECC1 for all groups with no significant differences ($p > 0.05$) between the groups. At 4 days after ECC1, 1 day after ECC2 for the 100, 90, and 80% groups, echo intensity was significantly increased ($p < 0.05$) from day 2; however, no significant differences were evident between the groups including the control group. Ultrasound images also demonstrated an increase in muscle thickness of the elbow flexors as shown in Figure 6. Maximal increase in the muscle thickness was generally found 4 days after ECC1 for all groups, and the amount of increase ranged from 2 to 11 mm; however, no significant differences between the groups were observed.

DISCUSSION

The most important finding of the present study was that the changes in criterion measures were not significantly

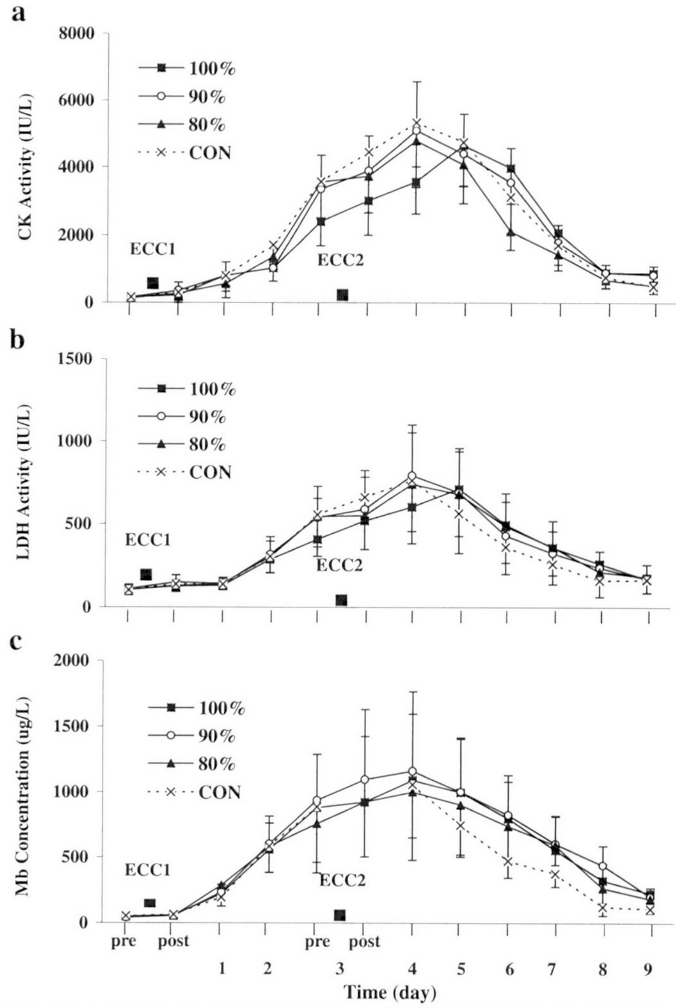

FIGURE 4. Changes in (a) serum creatine kinase (CK), (b) lactate dehydrogenase (LDH), and (c) myoglobin (Mb; means ± *SEM*) before and for 9 days following the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group, and the values immediately after ECC2 are shown as the second "post."

different between the groups not only 1–3 days following ECC1 but also 4–9 days after ECC1. This suggests that ECC2 did not have any influences on the changes in the measures following ECC1. These results confirmed the findings of the previous studies (8, 9, 23, 25, 28, 32) reporting that the second bout of eccentric exercise performed in the early recovery phase after the initial bout did not produce changes in indicators of muscle damage. Smith et al. (32) and Nosaka and Newton (25) showed that performing the same eccentric exercise 2 days after the initial bout did not affect the recovery of muscle function, responses of plasma CK activity, and development of DOMS. Similarly, Paddon-Jones et al. (28) and Chen (8) reported that the second bout of maximal voluntary isokinetic eccentric elbow flexors exercise performed 3 days after the first bout did not affect the changes in indicators of muscle damage. It should be noted that the intensity of the exercise in these studies was between 50 and 80% of the maximal strength, and the present study

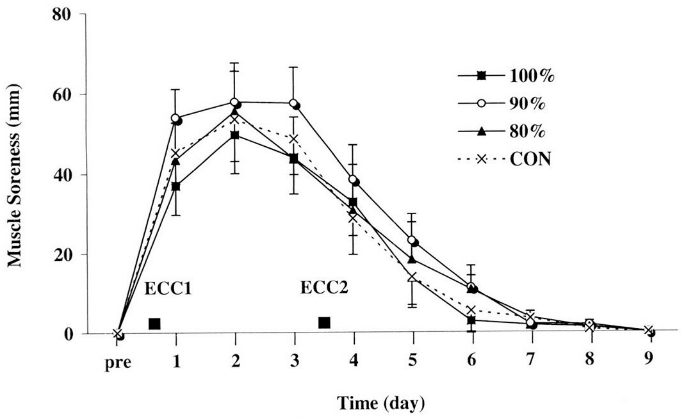

FIGURE 5. Changes in muscle soreness upon palpation (means ± *SEM*) before (pre, 0) and for 9 days following the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group.

used higher-intensity eccentric exercise for the first (100%) and second (80–100%) bout.

ECC1 resulted in significant decreases in MIF and ROM, increases in CIR, muscle thickness, and echo intensity, blood markers of muscle damage (CK, LDH, Mb), and development of DOMS for all groups (Figures 1–7). These changes were similar to the findings of previous studies (23–28, 32) in which a similar exercise protocol to the present study was used. It should be noted that the subjects in this study were athletes and used a heavy dumbbell (≈28 kg). It seems unlikely that untrained subjects could perform the eccentric actions of the elbow flexors of this weight. It appears that the long rest time between actions (45 seconds) helped the subjects to complete the demanding exercise. The similar strength decrement immediately after exercise of the present study compared with the previous studies (13, 23–28) in which untrained subjects were used suggest that the exercise was strenuous and unaccustomed even for the trained subjects who had experiences in resistance training, including for the elbow flexors. In fact, all subjects commented that they had never performed the eccentric exercise of the elbow flexors in the same way as that in this study. However, the effects of the exercise on the changes in muscle function appear to be less compared with the previous studies in which untrained subjects were used (13, 23, 24, 26, 28, 32). It seems likely that the elbow flexors of the subjects in the present study had obtained a protective effect against muscle damage to some extent.

The present study demonstrated that subjects were able to perform the second eccentric exercise bout with minor reduction (10%) of intensity without interfering the recovery process. It should be noted that subjects were still able to perform the second bout in which 80 or 90% of the dumbbell of the initial bout was used with sore and weak muscles. When ECC2 was performed, MIF was still approximately 30% lower than the pre-ECC1 level. It was thought that even the 80% load was difficult to perform the eccentric exercise precisely; however, all subjects in the 80% group were able to complete the 30 eccentric actions without spotting, as were most of the subjects (10/13) in the 90% group. This was surprising to us, and it is difficult to explain why it was possible for the subjects to

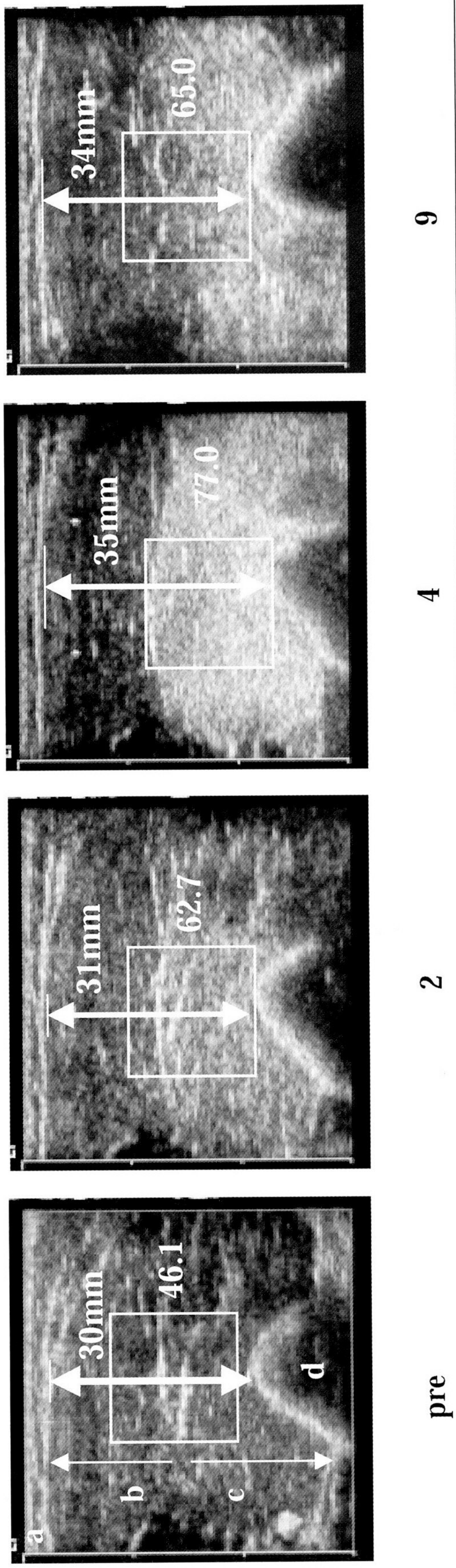

FIGURE 6. A series of transverse ultrasound images of a subject before (pre) and 2, 4, and 9 days after ECC1. In each picture, muscle thickness of the elbow flexors and echo intensity of the ROI (square) are shown. In the first picture, subcutaneous fat layer (a), biceps brachii (b), brachialis (c), and humerus (d) are indicated.

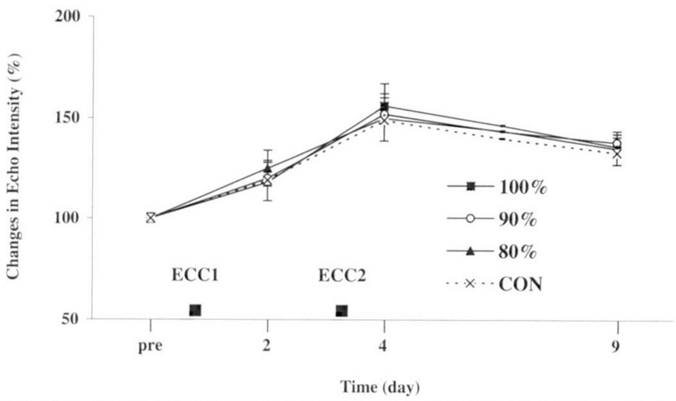

Figure 7. Normalized changes in echo intensity (means ± *SEM*) from the baseline (pre, 100%), 2, 4, and 9 days after the initial eccentric exercise (ECC1) for the 100%, 90%, 80%, and control (CON) groups. The second eccentric exercise (ECC2) was performed at 3 days after ECC1 by all groups except the control group.

perform the eccentric exercise with weak muscles. However, this may be related to their sporting activities and experiences of resistance training (13, 15). Previous studies showed that activations of motor units during muscle contractions were higher for trained than untrained subjects (30). If this is the case, the subjects in this study might have the ability to compensate the decrement of strength by maximizing potential recruitments. On the other hand, most of subjects (9/12) in the 100% group had difficulty in controlling the action, especially at weaker joint angles (from 140 to 170°), and spotting was required for this range. These subjects reported that the dumbbell was too heavy to control the movement. It seemed likely that subjects generated "100%" force of their capacity, but the 100% load was actually larger than 100% for them. Therefore, it is presumed that the upper limit of the intensity for the second bout of eccentric exercise of the elbow flexors is 90% of the first bout. It seems reasonable to assume that the stress to the elbow flexors was the largest for the 100% group, since the second exercise for the subjects in this group appeared to have exceeded their physiological limit. Thus, additional muscle damage for the 100% group was expected. However, changes in MIF and other measures following ECC2 for the 100% group were not significantly different from other groups. This suggests that the muscles that have been in a recovery phase from previous eccentric exercise are not affected by additional damaging stimuli, although some acute effects of exercise are seen immediately after exercise. This is different from other soft tissue damage such as laceration or muscle strain that relapses if the recovering muscles receive damaging stimuli (14, 35).

MIF decreased to about 60% of the pre-ECC1 value immediately after ECC1 for all groups (Figure 1); however, ECC2 resulted in larger decreases (about 54% of the pre-ECC1 level) in MIF immediately after exercise for all groups. The amount of decrease in MIF after ECC2 for the 100, 90, and 80% groups were about 3.9, 5.5, and 8.8%, respectively. Although there was a tendency that the higher the intensity, the smaller the decrement of MIF immediately after ECC2, no significant differences among groups were evident. This is important for the choice of load in resistance training when training is performed with recovering muscles from eccentric exercise. If trainees want to stimulate the damaged muscles maximally, the optimal weight would be around 80%, and no further benefit can be obtained by using 90% or higher. The difference between muscles also should be taken into account. The present study targeted the elbow flexors, but other muscles may respond differently to repeated bouts of eccentric exercise. It appears that the magnitude of decrease in muscle strength after eccentric exercise is smaller for the knee extensors compared with the elbow flexors (7, 12, 34). As shown in the present study, MIF decreases approximately 40% immediately after eccentric exercise of the elbow flexors (Figure 1), but 10–20% after a strenuous eccentric exercise of the knee extensors (7, 12, 34). This would indicate that the knee extensors are less susceptible to eccentric exercise–induced muscle damage than the elbow flexors (7). Since the muscle fibers are fusiform in the biceps, it is likely that the strain on the muscle fibers is very different than those fibers that are pinnate (such as the vastus lateralis). Therefore, the results of this study may not be generalized for other muscle groups.

The mechanisms to explain why recovering muscles from eccentric exercise do not suffer from additional eccentric exercise are unclear. It is well known that muscles become less susceptible to eccentric exercise–induced muscle damage once the muscles experience the same exercise (8, 12, 13, 20, 23). This protective effect is referred to as repeated bout effect (12, 13, 20, 23), and this effect has been shown to last several weeks to several months (12, 13, 20). As shown in previous studies (12, 20, 23), the protective effect seems to exist already in an early recovery phase such as 2–3 days after the first bout (8, 9, 23, 25, 28, 32). It may be that a group of stress-susceptible fibers are eliminated in the initial bout (2, 20). Because of the elimination of the stress-susceptible fibers after ECC1, there may be fewer muscle fibers to be damaged in ECC2. It is also proposed that muscle fibers become more resilient in the regeneration process (20, 23). However, it is not known how soon after exercise this adaptation occurs. It seems unlikely that the process of remodeling of muscle fibers to make them less susceptible to eccentric exercise–induced muscle damage is completed in 3 days after the initial bout, since regeneration of damaged tissue after eccentric exercise takes more than 1 week (7, 12, 13, 20). Although some possible mechanisms to explain the protective effect against eccentric exercise–induced muscle damage have been documented (12, 13, 20, 33), no clear explanation can be made for the effect shown in this study. Further studies are required to examine the mechanisms responsible for this rapid adaptation effect.

In conclusion, the present study showed that the second bout of high-intensity eccentric exercise of the elbow flexors did not result in further changes in MIF, ROM, CIR, soreness, CK, LDH, Mb, and ultrasound images, although there were significant acute changes in some of the measures immediately after exercise. This study confirmed the findings of previous studies (8, 9, 23, 25, 28, 32) that eccentric exercise performed in an early recovery phase from eccentric exercise did not exacerbate muscle damage and retard the recovery. Since all subjects were able to complete the second bout of eccentric exercise if the intensity was reduced 10–20% from the initial bout, it appears that muscles (at least the elbow flexors) have

great adaptability to eccentric loading and can repeat heavy eccentric training in 3 days with minor adjustment.

PRACTICAL APPLICATIONS

Athletes often perform training with sore muscles. If DOMS is a warning sign, sore muscles should not be exercised and a rest would be the best choice. The present study confirmed that repeating a high-intensity eccentric exercise 3 days after the initial bout, when DOMS still persisted, did not exacerbate muscle damage nor retard recovery. The intensity of the exercise was close to 1RM, but the 45-second rest between repetitions made it possible for subjects to perform 30 actions. All subjects were able to complete the second bout if the intensity was reduced 10–20% from the initial bout. It seems unlikely that this kind of training is performed at a gym, and most of trainings performed by athletes appear to be less injurious than that used in the present study. Nevertheless, no detrimental effects of the additional exercise bout were found in this study. The findings of this study suggest that athletes are able to perform maximal eccentric exercise every 3 days without additional muscle damage influencing the recovery process. Therefore, strength coaches can ask their athletes to perform high-intensity resistance training at least every 3 days without considering any averse effects on muscle function and pain sensation. This has confirmed the notion that DOMS can be ignored, and a chance to suffer from further muscle damage is minimal. However, it is another matter whether it is beneficial for athletes to perform such a training program. Moreover, it is important to differentiate eccentric exercise–induced muscle damage and muscle strains/soft tissue injury. If muscle pain is associated with the latter, an additional bout may be detrimental (14, 25, 35). Strength coaches and trainers should examine the cause of muscle soreness.

REFERENCES

1. ARMSTRONG, R.B. Mechanisms of exercise-induced delayed onset muscular soreness: A brief review. *Med. Sci. Sports Exerc.* 16:529–538. 1984.
2. ARMSTRONG, R.B. Muscle damage and endurance events. *Sports Med.* 3:370–381. 1986.
3. ATHA, J. Strengthening muscle. *Exerc. Sport Sci. Rev.* 9:1–73. 1981.
4. BAECHLE, T.R., R.W. EARLE, AND D. WATHEN. Resistance training. In: *Essentials of Strength Training and Conditioning* (2nd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2000. pp. 395–425.
5. BEATON, L.J., M.A. TARNOPOLSKY, AND S.M. PHILLIPS. Variability in estimating eccentric contraction-induced muscle damage and inflammation in humans. *Can. J. Appl. Physiol.* 27:516–526. 2002.
6. BROOKS, S.V., AND J.A. FAULKNER. Contraction-induced injury: Recovery of skeletal muscles in young and old mice. *Am. J. Physiol.* 258:C436–C442. 1990.
7. BYRNE, C., C. TWIST, AND R. ESTON. Neuromuscular function after exercise-induced muscle damage: Theoretical and applied implications. *Sports Med.* 34:49–69. 2004.
8. CHEN, T.C. Effects of a second bout of maximal eccentric exercise on muscle damage and EMG activity. *Eur. J. Appl. Physiol.* 89:115–121. 2003.
9. CHEN, T.C., AND S.S. HSIEH. The effects of repeated maximal isokinetic eccentric exercise on recovery from muscle damage. *Res. Q. Exerc. Sport* 71:260–266. 2000.
10. CHEUNG, K., P.A. HUME, AND L. MAXWELL. Delayed onset muscle soreness: Treatment strategies and performance factors. *Sports Med.* 33:145–164. 2003.
11. CLARKSON, P.M., AND M.J. HUBAL. Are women less susceptible to exercise-induced muscle damage? *Curr. Opin. Clin. Nutr. Metab. Care* 4:527–531. 2001.
12. CLARKSON, P.M., AND M.J. HUBAL. Exercise-induced muscle damage in humans. *Am. J. Phys. Med. Rehab.* 81:S52–S69. 2002.
13. CLARKSON, P.M., K. NOSAKA, AND B. BRAUN. Muscle function after exercise-induced muscle damage and rapid adaptation. *Med. Sci. Sports Exerc.* 24:512–520. 1992.
14. CONNOLLY, D.A.J., S.P. SAYERS, AND M.P. MCHUGH. Treatment and prevention of delayed onset muscle soreness. *J. Strength Cond. Res.* 17:197–208. 2003.
15. EVENS, W.J., C.N. MEREDITH, J.G. CANNON, C.A. DIARELLO, W.R. FRONTERA, V.A. HUGHER, B.H. JONES, AND H.G. KNUTTGEN. Metabolic changes following eccentric exercise in trained and untrained men. *J. Appl. Physiol.* 61:1864–1868. 1986.
16. FLECK, S.J., AND W.J. KRAEMER. *Designing Resistance Training Programs* (2nd ed.). Champaign, IL: Human Kinetics, 1997.
17. FOX, E.L., R.W. BOWERS, AND M.L. FOSS. *The Physiological Basis for Exercise and Sport* (5th ed.). Dubuque, IA: WCB Brown & Benchmark, 1993.
18. LAPOINTE, B.M., P. FREMONT, AND C.H. COTE. Adaptation to lengthening contractions is independent of voluntary muscle recruitment but relies on inflammation. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 282:R323–R329. 2002.
19. MCARDLE, A., W.H. DILLMANN, R. MESTRIL, J.A. FAULKNER, AND M.J. JACKSON. Overexpression of HSP70 in mouse skeletal muscle protects against muscle damage and age-related muscle dysfunction. *FASEB J.* 18:355–357. 2004.
20. MCHUGH, M.P. Recent advances in the understanding of the repeated bout effect: The protective effect against muscle damage from a single bout of eccentric exercise. *Scand. J. Med. Sci. Sports* 13:88–97. 2003.
21. NGUYEN, H.X., AND J.G. TIDBALL. Null mutation of gp91phox reduces muscle membrane lysis during muscle inflammation in mice. *J. Physiol.* 553:833–841. 2003.
22. NIKOLAOU, P.K., B.L. MACDONALD, R.R. GLISSON, A.V. SEABER, AND W.E. GARRETT. Biomechanical and histological evaluation of muscle after controlled strain injury. *Am. J. Sports Med.* 15: 9–14. 1987.
23. NOSAKA, K., AND P.M. CLARKSON. Muscle damage following repeated bouts of high force eccentric exercise. *Med. Sci. Sports Exerc.* 27:1263–1269. 1995.
24. NOSAKA, K., AND P.M. CLARKSON. Changes in indicators of inflammation after eccentric exercise of the elbow flexors. *Med. Sci. Sports Exerc.* 28:953–961. 1996.
25. NOSAKA, K., AND M. NEWTON. Repeated eccentric exercise bouts do not exacerbate muscle damage and repair. *J. Strength Cond. Res.* 16:117–122. 2002.
26. NOSAKA, K., AND M. NEWTON. Is recovery from muscle damage retarded by a subsequent bout of eccentric exercise inducing larger decreases in force? *J. Sci. Med. Sport* 5:204–218. 2002.
27. NOSAKA, K., M. NEWTON, AND P. SACCO. Delayed-onset muscle soreness does not reflect the magnitude of eccentric exercise-induced muscle damage. *Scand. J. Med. Sci. Sports* 12:337–346. 2002.
28. PADDON-JONES, D., D. MATHALIB, AND D. JENKINS. The effect of a repeated bout of eccentric exercise on induces of muscle damage and delayed onset muscle soreness. *J. Sci. Med. Sport* 3:35–43. 2000.
29. RINARD, J., P.M. CLARKSON, L.L. SMITH, AND M. GROSSMAN. Response of males and females to high-force eccentric exercise. *J. Sports Sci.* 18:229–236. 2000.
30. SALE, D.G. Neural adaptation to resistance training. *Med. Sci. Sports Exerc.* 20:S135–S145. 1988.
31. SAYERS, S.P., AND P.M. CLARKSON. Force recovery after eccentric exercise in males and females. *Eur. J. Appl. Physiol.* 84: 122–126. 2001.
32. SMITH, L.L., M.G., FULMER, D. HOLBERT, M.R. MCCAMMON, J.A. HOUMARD, D.D. FRAZER, E. NSIEN, AND R.G. ISRAEL. The impact of a repeated bout of eccentric exercise on muscular strength, muscle soreness and creatine kinase. *Br. J. Sports Med.* 28:267–271. 1994.

33. WARREN, G.L., K.M., HERMANN, C.P. INGALLS, M.R. MASSELLI, AND R.B. ARMSTRONG. Decreased EMG median frequency during a second bout of eccentric contractions. *Med. Sci. Sports Exerc.* 32:820–829. 2000.
34. WARREN, G.L., D.A. LOWE, AND R.B. ARMSTRONG. Measurement tools used in the study of eccentric contraction-induced injury. *Sports Med.* 27:43–59. 1999.
35. WEBBER, A. Acute soft-tissue injuries in young athletes. *Clin. Sports Med.* 7:611–624. 1988.
36. WILMORE, J.H., AND D.L. COSTILL. *Physiology of Sport and Exercise* (4th ed.). Champaign, IL: Human Kinetics. 2004.

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